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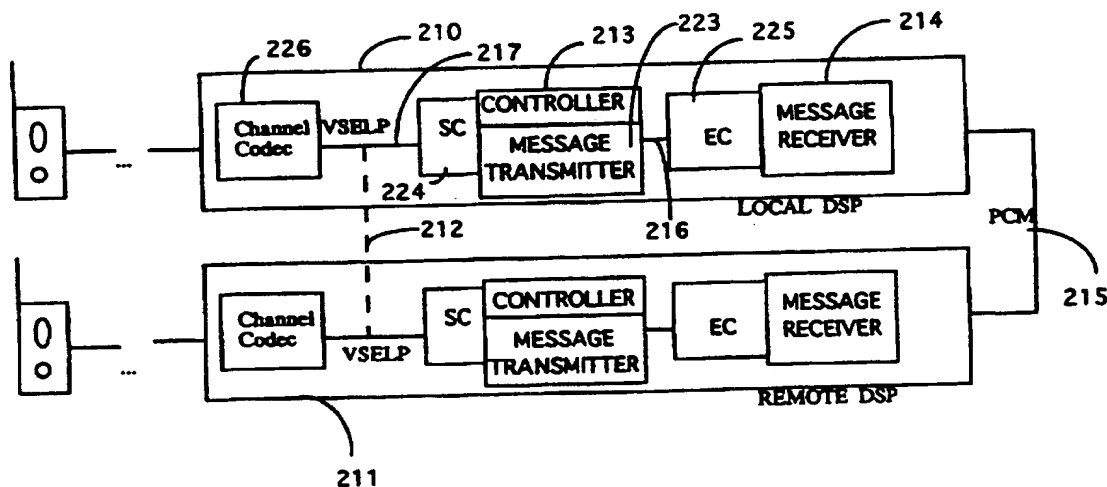
(57) Abstract

In a TDMA mobile-to-mobile connection, the end-to-end audio signal quality as well as system performance can be improved by providing digital signal processors the capability to automatically switch configuration such that each digital signal processor in a mobile-to-mobile communication connection can automatically identify a TDMA mobile-to-mobile connection and bypass the speech encoding and decoding processes within the digital signal processors. The two digital signal processors are virtually connected at the channel codecs.

SYSTEM FOR TDMA MOBILE-TO-MOBILE VSELP CODEC BYPASS

Field of the Invention

This invention relates to signal processing in a
digital cellular system and more particularly, to a method
of providing an automatic switching capability from a
tandem to a single Vector Sum Excited Linear Prediction
(VSELP) speech encoder/decoder configuration in a TDMA
mobile-to-mobile connection.

Background of the Invention

Digital signal processor (DSPs) are used in
digital mobile cellular radio systems to enable echo
cancellation, speech encoder/decoder (codec) functions and
channel encoder/decoder functions for TDMA channels. These
digital signal processors perform in some installations
echo cancellation on the switch side of the cellular
infrastructure. Some equipment manufacturers provide for
these functions on the cell site end of the cellular
system. In both cases, the speech and channel
encoder/decoder (codec) designs and implementations are
made to compliance with Communications Technology Industry
Association's (CTIA) Digital Cellular Interim Standard (IS-
54) specification.

In a TDMA mobile-to-land connection, audio
signals arriving at the digital signal processor from the
land source is first subject to echo cancellation. The
echo cancelled signal is then compressed into IS-54 VSELP
signal format with a 8:1 ratio and the compressed signal is
channel encoded and sent over the air to the mobile. VSELP
signal arriving at the mobile is channel decoded and then
used to reconstruct the original audio signal by the speech
decoder. The entire speech encoding and decoding process
introduces perceptible coding noise to the reconstructed
speech signal. Audio signal travelling in the reverse
direction (mobile to land) is subject to the same encoding

and decoding processes but with no echo cancellation by the digital signal processors.

A TDMA mobile-to-mobile connection is realized basically by connecting two TDMA mobile-to-land calls back
5 to back between two digital signal processors. Thus, an audio signal travelling in either direction is subject to two speech encoding and decoding processes operating in tandem. Thus, the coding noise introduced at each end degrades the quality of voice signal received by each
10 subscriber.

Accordingly, a requirement exist to reduce the amount of coding noise which is generated during mobile-to-mobile communication.

15 **Summary of the Invention**

With the design of the present invention, the digital signal processor is provided with the capability to automatically switch configuration such that two digital signal processors can automatically identify a TDMA mobile-
20 to-mobile connection and bypass the speech encoding and decoding processes within the digital signal processors. The two digital signal processors are virtually connected at the channel codecs. Thus enhancing the end-to-end audio signal quality as well as improving system performance.

25 According to an aspect of the present invention, there is provided a digital cellular radio system for enabling digital mobile radios to communicate with each other and the public switched telephone network via radio cell sites and a mobile switching office, said digital
30 cellular radio system having digital signal processor means for providing echo cancellation, speech encoding/decoding and channel encoding/decoding of audio signals, comprising:

a first digital signal processor for enabling echo cancellation, speech encoding/decoding and channel
35 encoding/decoding of audio signals from a local digital mobile telephone;

a second digital signal processor for enabling
echo cancellation, speech encoding/decoding and channel
encoding/decoding of audio signals from a remote digital
mobile telephone;

5   a message transmitter for transmitting in-band
signalling information to a remote digital signal
processor;

a message receiver for detecting in-band
signalling information at a local digital signal processor;

10   and

a controller for monitoring the transmission of
signalling information from said a remote message
transmitter to a local message receiver, wherein when said
local message receiver detects inband signalling

15   information from said remote message transmitter indicating
that a digital mobile-to-mobile connection is established,
said first and second digital signal processors can switch
to a by-pass mode to by-pass the speech encoding/decoding
and echo cancellation functions such that each digital

20   mobile radio communicate audio signal directly with each
other in a VSELP format via said channel encoding/decoding
function.

Brief description of the Figures

25   Figure 1 is a block diagram illustrating a
mobile-to-mobile connection over two digital speech
processors at the switch side of a network;
Figure 2 is a block diagram illustrating a
mobile-to-mobile connection with the codec by-pass feature

30   activated according to an embodiment of the invention;
Figure 3 is a representation of a frame of 8-bit
PCM samples with mobile-to-mobile protocol bit stealing
according to an embodiment of the invention;
Figure 4 is a representation of a frame of VSELP

35   signal according to another embodiment of the invention;
Figure 5 is an illustration of the receiver state
diagram;

Figure 6 is an illustration of the transmitter
state diagram;

Figure 7 is a table showing the transmitter state
machine output for the diagram of figure 6;

5   Figures 8a-8g are flow diagrams showing the
operations of the controller, message receiver and
transmitters;

Figures 8h and 8i are flow diagrams of the PCM
and VSELP input handler;

10   Figure 9 is a diagram illustrating the schedule
of inter-application communication for PCM and VSELP signal
transfers;

Figure 10 is a table describing the speech
decoder input information;

15   Figure 11 is a diagram illustrating the TDMA
frame structure between the echo canceller and speech
codec; and

Figure 12 is a block diagram illustrating the
different signal paths and TDMA connections for mobile-to-
20   mobile communication.

Detailed Description of the Preferred Embodiment

Referring to Figure 1, we have shown a block
diagram illustrating a network connection between two
25   cellular subscribers. In this embodiment, the subscribers
communicate over the Public Switched Telephone Network via
separate telephone exchanges. However, in some instances,
it is possible for two subscribers to communicate with each
other via the same telephone exchange. For example, a
30   mobile telephone exchange such as Northern Telecom's DMS-
MTX can be connected to as many as 250 cell sites. Thus,
it is possible that within a small city, all cell sites are
serviced by the same mobile exchange. Accordingly, a
single mobile exchange could in effect service two
35   subscribers that require a communication link to each
other.

In Figure 1, a first subscriber 100 is
communicating with a second subscriber 120 via a first cell
site 110 and mobile telephone exchange 112 and a second
cell site 121 and mobile telephone exchange 122. The first
5   and second mobile telephone exchanges communicate with each
other over the PSTN 130.

As indicated above, the Digital Signal Processors
113 and 123 can either be part of peripheral equipment
connected to the switch or part of the cell site
10   infrastructure. The digital signal processors provide the
capability of voice transcoding from mu-law (or A-law PCM
depending on which standard is being used) to VSELP (Vector
Sum Excited Linear Prediction) and vice-versa. Multiple
DS-1 carrier interface circuits are used to distribute
15   voice and control messages to and from the cell sites via
trunks 114 and 124.

Digital signal processors are generally comprised
of multiple signal processors commercially available from a
number of suppliers. One such processor is Motorola's
20   560001 DSP.

In a TDMA mobile-to-land connection, audio
signals arriving at the digital signal processor from the
land source, i.e. PSTN 130, is first subject to echo
cancellation at echo canceller 115. The echo cancelled
25   signal is then compressed at speech codec 116 into IS-54
VSELP signal format with a 8:1 ratio and the compressed
signal is channel encoded at channel codec 117 and sent
over the air to the mobile subscriber 100 via the radio
unit or cell site 110. VSELP signal arriving at the mobile
30   is channel decoded and then used to reconstruct the
original audio signal by the speech decoder. The entire
speech encoding and decoding process introduces perceptible
coding noise to the reconstructed speech signal. Audio
signal travelling in the reverse direction (mobile to land)
35   is subject to the same encoding and decoding processes but
with no echo cancellation by the digital signal processor.
Echo cancellation is provided on the PSTN side of the

connection to eliminate the effects of delays introduced by
the speech coding and TDMA transmission processes. The
connection from the digital signal processor to the mobile
is equivalent to a four wire connection with substantial
5   delays due to speech coding and TDMA transmission. The
echo occurs on the network side and is therefore cancelled
in the digital signal processor.

When a TDMA mobile-to-mobile connection such as
shown in Figure 1 is realized, two TDMA mobile-to-land
10   calls are basically connected back to back between two
digital signal processors on the switch side in this case.
An audio signal travelling in either direction is subject
to two speech encoding and decoding processes operating in
tandem. Thus, the coding noise introduced at each end
15   degrades the quality of voice signal received by each
subscriber.

The codec bypass feature of the present invention
is designed for TDMA mobile-to-mobile communications
realized with two bypass-capable digital signal processors
20   connected on the switch side. Here, we define connected on
the switch side as meaning that the digital signal
processor operations are done at the switch end instead of
the cell site end of the cellular infrastructure. As
indicated before, some cellular infrastructures have
25   digital signal processors connected at the base station end
of the link such that echo cancellation, speech coding and
channel coding is done at the cell site.

Codec bypass realization is based on determining
that one digital signal processor is directly linked with
30   another (or itself) in a mobile-to-mobile connection. The
bypass feature consists of two components: a digital signal
processor communication protocol and speech codec bypass
mechanism.

As will be illustrated with reference to Figure
35   2, the digital signal processor communication protocol is
used to set up communication between two enhanced digital
signal processors 210 and 211 in the same mobile-to-mobile

connection. Upon successful handshakes, each digital
signal processor activates the bypass mechanism to transmit
the mobile audio signal in VSELP format to the other
digital signal processor, and speech codec bypass is
5   completed. Note that broken line 212 is not a physical
path, but represents a virtual or logical path between the
two digital signal processors.

The communication protocol is active at all time
to establish and maintain communication with the remote
10   digital signal processor. In the embodiment of Figure 2,
the local digital signal processor is indicated at
reference numeral 210 and the remote digital signal
processor at reference numeral 211. The communication
process is done via inband signalling and is independent of
15   the echo cancellation, speech encoding/decoding and channel
encoding/decoding applications. The communication protocol
operations are transparent to the system users in all TDMA
connections: mobile-to-land and mobile-to-mobile.

As will be explained later in further detail, the
20   protocol design consists of three functional modules: a
message receiver, a controller, and a message transmitter.
They are responsible for in-band signal detection, dialogue
and by-pass control and in band signal transmission,
respectively. Operations of the message receiver and the
25   message transmitter are independent of each other. The
message controller serves as a link between them to update
the message transmitter state on message receiver outputs.

An outgoing signal 215 of a bypass-capable
digital signal processor for a TDMA channel is transmitted
30   to the switch at a rate of 64 Kbps in both PCM or codec
bypass modes. The signal is composed of two types of
information--local mobile user audio signal and in-band
signalling information. Format of the user audio signal
and in-band signal are switched/changed in different stages
35   of the inter-processor communication process.

Local mobile audio signal is transferred to the
remote mobile in either of two formats. In non-VSELP

bypass mode, the information is sent as a sequence of 8-bit
PCM samples. In codec bypass mode, frames of VSELP signal,
augmented to a 64 Kbps data stream, are sent.

Two types of protocol messages are defined.
5   Specifically, two messages of equal length are available
for the PCM sample sequence from the speech decoder output
216 and one message is for the VSELP byte stream from the
speech decoder input 217 (see Figure 2).

The first message defined for the PCM sequence is
10   the digital signal processor identifier, and the second is
the acknowledgment to a remote DSP identifier. By default,
the local digital signal processor 210 transmits speech
decoder output together with DSP identifiers in the reverse
direction toward the switch. These messages are
15   transmitted at a rate of 400 bits per second on the 64 Kbps
digital link. Due to limitations of channel bandwidth in
PCM transmission, bit stealing is in place to realize
inband signalling. Each PCM message bit is sent by
replacing a single user audio signal bit from an 8-bit PCM
20   sample. This bit stealing scheme takes place at a regular
interval. The bit location in a PCM byte and the bit
stealing interval are selected to minimize the perceptual
impact on the PCM signal at the receiver.

In bypass mode, each frame of 20 ms VSELP signal
25   is also transmitted at a rate of 64 kbps. The protocol
prefixes the outgoing VSELP information, 159 bits for a 20
ms frame, with the VSELP message for VSELP signal
identification. Note that the Table shown in Figure 10
shows the 159 bit frame plus 3 CRC bits for a total of 162
30   bits. Given that a frame of VSELP data occupies a fraction
of the bandwidth provided by the digital channel, the
protocol augments the VSELP byte stream with additional
information pertinent to the VSELP frame such as VSELP
check sum.

35   Figure 3 shows a frame of 8-bit PCM samples
superimposed with PCM message information. Here, X
represents a PCM information bit and O is a message bit.

9

In the figure, bit stealing takes place on every third PCM sample. However, during an actual call, PCM bit stealing would be done at 1 bit every 20 samples. This rate is of course dependent on the operational parameters of the

5   system.

As will be defined later, Figure 4 illustrates the structure of a VSELP frame containing a VSELP message and VSELP signal.

A Receiver State Machine and a Transmitter State

10 Machine govern the protocol operations. The receiver state machine has two states as shown in Figure 5 for PCM and VSELP inputs, respectively, from the switch. State transitions occur on a 20 ms frame basis. The system enters and stays in state R1 for 20 ms in the absence of a

15 VSELP message at the beginning of the input frame. It enters and stays in state R2 for 20 ms immediately after a VSELP message is detected. Under normal TDMA mobile-to-land communication, the machine always operates in state R1. During codec bypass in a TDMA mobile-to-mobile call,

20 it operates in state R2.

The transmitter state machine, shown in Figure 6, has four states--T1 through T4. Each state dictates the type and format of local mobile signal to the remote digital signal processor, if available. Each state also

25 determines the type of messages to write to the output stream--DSP Identifier, DSP Acknowledgment, or VSELP message. State transition is prompted by the received remote DSP messages.

The table of Figure 7, shows the digital signal

30 processor output definitions. Each state is characterized by the transmission of a single user signal format and protocol message type. A protocol message is always written to the output 216 (see Figure 2). State T1 is the system's initial and default operating state. In case of a

35 loss of synchronization with the remote DSP message, the transmitter state machine returns to state T1 regardless of the current state. In state T1, the message transmitter

223 superimposes PCM message "DSP Identifier" on the output
PCM sample sequence. This is so even in the absence of a
remote bypass-capable digital signal processor. The
protocol does not switch to state T2 until the presence of

5   a remote digital signal processor 211 is confirmed by an
incoming "DSP Identifier" or multiple "DSP Acknowledge" at
receiver 214. The "DSP Acknowledge" message is sent by the
transmitter in state T2 to acknowledge the receipt of the
remote "DSP Identifier". The transmitter transmits the

10   user signal in VSELP format in both states T3 and T4. The
protocol switches to state T3 when a "DSP Acknowledge" to
its own identity is received from the remote digital signal
processor. The objective of this handshaking process is to
ensure a sane two-way communication and smooth transition

15   before establishing the connection in VSELP bypass mode.
State T4 is the final state in which the TDMA mobile to
mobile connection is in full duplex codec bypass mode.
Although both states T3 and T4 specify VSELP signal
transmission, state T4 is entered only when the input to

20   the digital signal processor is also in VSELP format. A
fifth state, not shown in Figure 6, is entered when special
system messages are received. In this state, the speech
decoder output thus proceeds unchanged to the echo
canceller 225 and the PSTN 130.

25   State T1 is entered again whenever there is a
removal of the special messaging or a loss of
synchronization.

        This provision is necessary in applications such
as mobile activated DTMF tone generation where a DTMF tone

30   is generated on the Speech Coder and available in PCM
format only. This design also provides the switch with the
capability to manually disable the codec bypass feature.
Figures 8a to 8i are flowcharts representing the operating
instructions of the transmitter and receiver state

35   machines, message transmitters and receivers and the PCM
and VSELP input handler. Figure 8a shows the controller
flowchart. Since a state transition occurs on a 20 ms.

basis, the controller is called once every 20 ms. Figure
8b shows the receiver update flowchart as initiated by the
controller. That is, the receiver state is set to R1 or R2
depending on whether a VSELP message is received. The
5   transmitter state machine is updated through 4 separate
states as shown in Figure 8c and 8d, where state T1 is the
system's initial and default operating state. Figure 8e is
the operations flowchart of the message transmitter 223
shown in Figure 2. The transmitter is called once every 20
10 ms. Each PCM message is transmitted over multiple 20 ms.
frames of PCM samples. The VSELP signal is split up and
written into the least significant part of the output
buffer entries. The most significant part of the entries
has a bit pattern resembling low amplitude PCM samples.
15 This is done in order to reduce the perceptual impact when
the VSELP signal is falsely received as PCM samples. The
operations flowchart of the Message receiver 214 of Figure
2 is shown in Figure 8f and 8g. The message receiver is
called once for every input sample. The beginning of an
20 outgoing PCM or VSELP message is synchronized with the
beginning of a 20 ms. frame by the message transmitter.
Detection of a remote PCM or VSELP message therefore
defines the beginning of the remote framing structure seen
by local digital signal processor.
25   Figures 8h and 8i describe the routine used to
handle linearized PCM samples or VSELP signal from the
switch. The PCM and VSELP handler routine is designed to
properly read the PCM or VSELP input data at different
operating mode. The PCM and VSELP handler routine is done
30 at the speech encoder input. Note that in Figure 8i, the
half cycle raised cosine window is off by default. It is
turned on at VSELP to PCM transition for the first complete
PCM sample frame after the transition. The PCM samples are
attenuated by the cosine window who's weight ranges from
35 zero to unity such that a smooth transition becomes
effective with zero initial state. The PCM input samples
to this routine are in 16-bit linear format.

12

As indicated earlier, the protocol design consists of three functional modules: a message receiver 214, a controller 213, and a message transmitter 223. They are responsible for in-band signal detection, dialogue

5   control and in band signal transmission, respectively. Operations of the message receiver and the message transmitter are independent of each other. The message controller serves as a link between them to update the message transmitter state on message receiver outputs.

10   The function of the message receiver 214 is to detect and identify in-band signalling information in the input from a remote digital signal processor 211. It operates on a sample by sample basis asynchronous to the local digital signal processor TDMA framing structure.

15   By default, the local digital signal processor 210 receives PCM input signals from the switch side and the message receiver 214 attempts to acquire synchronization with incoming protocol messages. During PCM signal reception, the message receiver 214 monitors the designated

20   bit of each input byte. It is only after multiple DSP identifiers are received that the presence of a remote digital signal processor 211 and a clear digital connection is confirmed. Upon validating the DSP identifiers, the message receiver operations are in synchronization with the

25   framing structure of the remote digital signal processor 211. The message receiver continues monitoring the input byte stream for new protocol messages. Remote digital signal processor to local digital signal processor codec bypass on virtual or logical path 212 is confirmed upon

30   receiving VSELP message at the beginning of a remote incoming frame. Synchronization with the remote digital signal processor is lost when the message receiver fails to detect new PCM or VSELP messages in the input, and the message receiver returns to operate in the synchronization

35   acquisition mode.

The controller 213 operates the transmitter and receiver state machines on message receiver outputs and

also on the presence of any special messages to determine the proper operating mode of the state machines.

The message transmitter 223 is responsible for writing the output buffer with the local mobile audio signal and the protocol messages in the proper format. It superimposes the "DSP identifier" or "DSP Acknowledge" messages on the DSP PCM output sequence, or it constructs a VSELP output frame with VSELP message and information bytes. The table of Figure 7 shows the transmitter output format and the corresponding message types for different transmitter states.

The message transmitter operation is driven by the controller 213. The operation is also in synchronization with the local TDMA framing structure. As shown in Figure 3 and Figure 4, each message bit is written to well-defined locations in the 20 ms (160 bytes) output byte sequence. Each selected message is transmitted in full length. The transmitter does not write a new message to the output stream until the last bit of the current message is sent.

The loose coupling between the message receiver and message transmitter of the protocol design has two advantages. First the message receiver does not have to be in synchronization with the local TDMA framing structure. Due to the effects caused by transmission delay, a 20 ms frame from the remote digital signal processor is not necessarily synchronized to a local TDMA frame upon arrival. The protocol design allows the message receiver to lock onto the input message regardless of the local TDMA timing. The second advantage is that data type traversing in opposite directions on the DSP/DSP digital link can be asymmetrical. The signal format need not be PCM/PCM or VSELP/VSELP. While the local digital signal processor may be transmitting the local mobile user information in VSELP format, the remote digital signal processor may be responding with PCM samples due to.

14

Echo Canceller Application

During the non-bypass mode of the bypass-capable
digital signal processor, the speech codec 224 sends the
160 samples every 20 ms to the echo canceller 225 directly
5   in 8-bit PCM format. The linear to PCM conversion
operations are executed directly on the speech decoder
output on the speech codec. The resulting PCM bytes are
delivered to the echo canceller 225 from the speech codec
and then written to the digital signal processor output 215
10   on the switch side for the designated TDMA channel without
further signal processing on the echo canceller .

During codec bypass in the local digital signal
processor 210 to remote digital signal processor 211
direction, the user audio signal data is taken directly
15   from the speech decoder input--channel decoder output-- 217
in the form of VSELP compressed signal, framed with VSELP
messages. It is sent via the echo canceller 225 to the
digital signal processor output. A total of 160 bytes--in
either PCM or VSELP format--is received at the input/output
20   buffer of the echo canceller 225 for each TDMA voice
channel every 20 ms.

The bypass-capable echo canceller software
transmits the echo cancelled samples to the speech codec in
a 16-bit linear format, in two bytes via the input/output
25   buffer. In addition, signalling information from the
message receiver on the echo canceller is transmitted to
the controller on the speech codec. This information
includes the number of remote VSELP bytes in the
input/output buffer frame, remote message type and remote
30   message error count.

The echo canceller 225 for a TDMA channel is
skipped as soon as the presence of a remote digital signal
processor 211 is confirmed by the message receiver 214.
Also, the canceller is not required since no hybrid is in
35   the direct digital signal path. After a remote digital
signal processor is confirmed, input samples to the echo
canceller from the remote digital signal processor will

undergo PCM to linear conversion only. The resulting 16-
bit linear samples are written to the echo canceller
input/output buffer for the speech codec as if they were
echo cancelled samples.

5   VSELP input bytes from the remote digital signal
processor are processed differently. When an incoming 20
ms frame--160 bytes--of VSELP signal is confirmed by the
message receiver 214, every validated VSELP byte from the
remote digital signal processor 211 is directly written,

10   accompanied by a zero byte, to the input/output buffer for
the corresponding speech codec .

           Thus, a total of 320 bytes are sent to the speech
codec by the echo canceller every 20 ms via the same
buffer. The signal is echo cancelled in the absence of a

15   remote digital signal processor. Otherwise, the signal is
sent directly from the echo canceller to the input/output
buffer for the speech codec.

Speech Codec Application

20   The controller and message transmitter on the
Speech Codec are invoked once every 20 ms. The controller
takes input from the message receiver in each input/output
buffer and executes the state machine to determine the next
transmitter state (see Figures 8a-8g). The message

25   transmitter serves as a slave to the controller and writes
the 20 ms input/output buffer with the proper data and
message for the echo canceller.

           Figure 9 shows an example of the schedule of the
speech codec communication with the echo canceller and

30   channel coder. With reference to Figure 2 and 9, we note
that after the VSELP signal transfer from channel codec 226
to speech codec 224 is completed, the speech decoder 224
and the message transmitter 223 are activated in this
order. In the case of codec bypass, in the local digital

35   signal processor to remote digital signal processor
direction, the decoder is not activated. The output of
this process is loaded in time slot "X" to the input/output

buffer to be sent to the echo canceller within the same 20
ms TDMA frame (figure 9).

After the speech codec receives the input/output
buffer from the echo canceller, the controller is activated
5   to update the state machine based on new information from
the message receiver. The speech encoder is invoked, if
needed, to compress the linear input samples. The
compressed speech signal is sent to the channel codec in
time slot "x" in the next 20 ms frame.

10   Two types of data can be transferred from the
speech codec to the echo canceller. This data can be the
speech decoder output or the speech decoder input,
depending on the state of the local message transmitter.
In either case, 160 bytes are written to the input/output
15   buffer for the echo canceller .

In the bypass-capable digital signal processor
software design, the linear to 8-bit mu-law/A-law PCM
conversion are activated for speech decoder output samples
in non-VSELP bypass mode. The resulting PCM samples
20   --sequence of 8-bit bytes-- are superimposed with a PCM
message as illustrated in Figure 3.

During codec bypass, the message transmitter
writes directly into the input/output buffer the speech
decoder input in VSELP format. Each 20 ms frame of VSELP
25   signal to the speech decoder input consists of 159 bits of
compressed speech signal and 3 bits of CRC state
information. This information is presented to the speech
decoder input in 28 bytes in the order as shown in the
table of Figure 10.

30   The message transmitter breaks up these 28 VSELP
information bytes into 4-bit units and writes every unit
into a separate input/output buffer entry with the most
significant units first. Specifically, each 4-bit unit is
written to the input/output byte starting at the second
35   least significant bit or bit one "1" to prevent potential
conflict with T1 signalling information on a T1 trunk
between two digital signal processors in a mobile-to-mobile

call. The remaining most significant bits of each
input/output buffer byte is filled with a fixed pattern
such that the complete byte is seen as a mu-law/A-law PCM
code of small magnitude. This is done to reduce the
5   undesired perceptual effect when the VSELP signal is
falsely recognized or received as PCM signal.

Thus, the input/output buffer contains the VSELP
message bytes followed by 28X2 size VSELP information
bytes. An additional check sum byte is appended to the
10   information bytes. The remaining input/output buffer
entries are also filled with the same fixed pattern for the
same purpose.

Two types of data received from the remote
digital signal processor are transferred - 16-bit linear
15   sample sequence and VSELP byte stream.

Due to the effects of transmission delay, a frame
of VSELP compressed signal from the remote digital signal
processor may not coincide with the local 20-ms frame
structure in a direct TDMA mobile-to-mobile connection.

20   As illustrated in Figure 11, the content of a
local 20 ms frame of data from the echo canceller to the
speech codec has the following combinations:
—   all linear samples (frame i)
—   linear samples followed by VSELP signal as in PCM
25   to VSELP transition (frame j)
—   VSELP signal from two adjacent 20 ms frames
(frame k, see section C below)
—   VSELP signal from one single 20 ms frame (frame
k, see section C below)
30   —   VSELP signal followed by linear samples as in
VSELP to PCM transition (frame l).

As indicated earlier, the echo canceller sends
to the speech codec signalling information in addition to
the user speech signal. This signalling information
35   includes a VSELP byte count in each 20 ms input/output
buffer transfer. A count of zero indicates an all linear
sample transfer and a non-zero count denotes the number of

valid VSELP byte available in the transfer. The content of
each input/output buffer is read with special care in the
presence of VSELP signal. Examples of PCM and VSELP signal
transfer and management, implemented in the bypass-capable
5   digital signal processor load are as follows:

A. All linear sample transfer
             When the VSELP byte count is zero, the complete
20 ms frame of linear samples is processed by the speech
10   encoder as usual. Remote 20 ms framing structure has no
effect on the local encoding process.
B. Non-zero VSELP byte count following an all linear sample
transfer
             This combination signals a PCM to VSELP --non-
15   VSELP to codec bypass-- transition. One of two actions are
taken to reconstruct a frame of VSELP information for the
channel encoder. The selection decision is based on
completeness of VSELP information in each input/output
buffer transfer.
20   If the relationship between the local and remote
framing structure is such that all remote VSELP information
for a 20 ms speech frame reproduction falls in a single
input/output buffer transfer, the VSELP information is
reformatted and sent to the channel codec (CC) directly
25   without invoking the speech encoder. The reformatting
process involves extracting and concatenating the 4-bit
units, most significant units first, to reconstruct the 28
VSELP information bytes.
             If the framing relationship is such that the
30   remote VSELP information for each 20 ms speech frame
crosses the boundary of two adjacent local frames, the
VSELP information is available in two input/output buffer
transfers. The VSELP information available in the current
local frame is stored in memory to be combined with the
35   remaining VSELP information available in the next transfer.
After being copied to memory, this partial VSELP
information in the input/output buffer is replaced by

linear samples of zero amplitude. The entire frame in the
input/output buffer is then considered to contain all
linear samples and delivered to the speech encoder to be
compressed.

5   C. Consecutive frames with non-zero VSELP byte counts
                During remote to local digital signal processor
bypass, consecutive input/output buffer frames from the
echo canceller to the speech codec are filled up with VSELP
signal. The VSELP byte count equals its maximum and
10   remains constant until the local digital signal processor
loses synchronization with the remote VSELP signal. During
a VSELP to PCM --VSELP to non-VSELP bypass-- transition,
the local 20 ms frame contains partly VSELP signal and
partly PCM linear samples with the VSELP byte count less
15   than its maximum.
       •   STABLE codec BYPASS: ALL VSELP TRANSFER
       If there is enough VSELP information for a 20 ms speech
       reproduction, the VSELP bytes are reformatted and sent.
       Otherwise the buffer contains two sets of partial VSELP
20   information from two adjacent 20 ms frames. In this case,
       a frame worth of VSELP information is reconstructed with
       the partial VSELP information stored in the memory from the
       previous input/output buffer transfer and the first set of
       VSELP information available in the current input/output
25   buffer transfer. The reconstructed VSELP information is
       reformatted and sent to the channel codec. The memory is
       then updated with the second set of VSELP information to be
       used in the next frame.
                VSELP SYNCHRONIZATION LOSS: PARTIAL VSELP
30   TRANSFER
                If there was enough VSELP information for a 20 ms
       speech reproduction in the previous input/output buffer
       transfer, the entire input/output buffer transfer is
       processed as all linear samples by the speech encoder. If
35   there is partial VSELP information stored in the memory, it
       should be combined with the partial VSELP information in

the current frame reconstruct a frame worth of VSELP
information as in the "All VSELP Transfer" case above.

Thus, the speech encoder is skipped whenever
there is enough VSELP information for a 20 ms speech frame
5   to reconstruction. Otherwise, all linear samples from the
echo canceller are processed by the speech encoder. In
either case, the speech codec presents to the channel
codec the VSELP compressed information in the same format.
Before the speech encoder/decoder is reactivated, the coder
10   state is reset. This ensures that the coder will not start
from an unknown state. After the transition from bypass to
non-bypass, a smoothing cosine weighting function is
applied to the first PCM frame arriving from the remote
processor to suppress any transition noise.
15

Cyclic Redundancy Check (CRC)

As shown in Figure 12, a mobile-to-mobile TDMA
call consists of three signal paths. Two of the paths are
over the air between the mobiles and the respective digital
20   signal processors, and the third path is between the two
digital signal processors. Mobile-to-mobile TDMA calls are
subject to channel errors on these three paths, though the
error rates are not the same.

According to the IS-54 specification, each VSELP
25   speech decoder runs a state machine driven by CRC
conditions of the channel between the mobile and the land
terminals. In the presence of continuous CRC errors, the
speech decoder replicates the Linear Prediction
Coefficients (LPC) information and frame energy from the
30   previously received CRC error free transmission. In the
latter case, an attenuation factor is applied. The bypass-
capable digital signal processor load is designed in such a
way that the mobile-to-mobile feature is transparent to the
mobiles. The principal of the design is to make the tandem
35   links look like a single TDMA channel to the end users. In
a mobile-to-mobile connection, the IS-54 specified state
machine is activated once only by the receiving mobile in

response to a CRC error on path "L1" and/or path "L3". The text below details the operations involved in response to a CRC error.

Lets assume that a CRC error is detected on path

5 "L1" in the reverse direction by the channel decoder of "S1". Instead of exercising the state machine to replicate the LPC and frame energy as in a TDMA mobile-to-land connection, "S1" running in codec bypass mode would pass the 3-bit CRC state information together with the received

10 VSELP signal to channel encoder in "S2". In addition to the defined IS-54 VSELP signal, the speech encoder also sends to the channel encoder in "S2" the received CRC status. A flag in the channel encoder is set for a non-zero CRC state from "S1" and clear otherwise. The channel

15 encoder computes the CRC value for the received VSELP signal if the flag is set.

Instead of transmitting the calculated CRC along with the VSELP signal to mobile "M2", the channel encoder sends the 1's complement of the calculated CRC together

20 with the VSELP signal for the first 6 consecutive CRC failures. A CRC mismatch is effectively forced on mobile "M2". In effect, a CRC error on path "L1" is seen by mobile "M2" as a CRC error on path "L3" and acted upon accordingly. The value of the 3-bit CRC state information

25 received from "S1" by the speech encoder in "S2" is immaterial and is discarded after.

Transmission errors on path "L2" during codec bypass is monitored with a VSELP check-sum measure. During codec bypass, a VSELP check-sum is calculated on the

30 outgoing 3-bit CRC state information and the 12 most perceptually significant VSELP bits by the message transmitter. The check-sum figure is transmitted to the remote digital signal processor in a VSELP frame. Upon receiving a frame of VSELP information, the remote digital

35 signal processor calculates a new VSELP check-sum on the received 3-bit CRC state information and the received VSELP bits. The calculated VSELP check-sum is compared to the

received VSELP check-sum of the same frame. If the two check-sums are different, a "CRC error" on path "L2" is detected and the remote channel encoder is signalled as in the previous paragraph.

5   Only one state machine for VSELP signal replication is activated in each end-to-end TDMA mobile-to-mobile connection. Continuity of state machine operation for signal replication is ensured. In the case with CRC errors present on more than one paths, the reconstructed

10   signal frame energy is attenuated gradually as specified in IS-54 till total muting. If two independent state machines are activated in response to the consecutive or simultaneous CRC errors, fluctuation in the reconstructed signal frame energy will be observed.

15   The CRC computed is sent without modifications on the seventh or subsequent consecutive CRC failure. Instead, the frame energy 'R0' is set to zero to force a complete muting of the mobile audio signal on mobile 'M2'.

WHAT   IS   CLAIMED:

1.   A digital cellular radio system for enabling
digital mobile radios to communicate with each other and
5   the public switched telephone network via radio cell sites
and a mobile switching office, said digital cellular radio
system having digital signal processor means for providing
echo cancellation, speech encoding/decoding and channel
encoding/decoding of audio signals, comprising:
10   a first digital signal processor for enabling
echo cancellation, speech encoding/decoding and channel
encoding/decoding of audio signals from a local digital
mobile telephone;
             a second digital signal processor for enabling
15   echo cancellation, speech encoding/decoding and channel
encoding/decoding of audio signals from a remote digital
mobile telephone;
             a message transmitter for transmitting in-band
signalling information to a remote digital signal
20   processor;
             a message receiver for detecting in-band
signalling information at a local digital signal processor;
and
             a controller for monitoring the transmission of
25   signalling information from said a remote message
transmitter to a local message receiver, wherein when said
local message receiver detects inband signalling
information from said remote message transmitter indicating
that a digital mobile-to-mobile connection is established,
30   said first and second digital signal processors can switch
to a by-pass mode to by-pass the speech encoding/decoding
and echo cancellation functions such that each digital
mobile radio communicate audio signal directly with each
other in a VSELP format via said channel encoding/decoding
35   function.

2. A digital cellular system as defined in claim 1, wherein communication between said first and second digital signal processors comprises a mobile user audio signal and in-band signalling information.

3. A digital cellular system as defined in claim 2, wherein the audio signal and in-band signalling information is transmitted as a PCM sequence when in non-VSELP mode and transmitted in frames of VSELP signal when in echo cancellation and speech codec by-pass mode.

4. A digital cellular system as defined in claim 3, wherein said PCM sequence comprises an 8-bit PCM sequence and said frames of VSELP signal comprises a VSELP signal augmented to a 64 kbs data stream.

5. A digital cellular system as defined in claim 3, wherein PCM in-band signalling is achieved, by replacing a user's audio signal bit with a bit of a PCM message over a number of audio signal frames.

6. A digital cellular system as defined in claim 5, wherein said PCM in-band signalling information comprises at least one of a digital signal processor identifier message and a digital signal processor acknowledgment message.

7. A digital cellular system as defined in claim 6, wherein said user audio signal bit replacement is done at a pre-selected interval small enough to reduce the time delay required to switch to a by-pass mode, but large enough to minimize the perceptual impact on the PCM signal at the receiver.

8. A digital cellular system as defined in claim 7, wherein said pre-selected interval is 1 bit every 20 samples.

25

9.   A digital cellular system as defined in claim
8, wherein said DSP identifier and DSP acknowledgment
messages are made up by replacing 16 user audio signal bits
with message bits over a number of audio signal frames.

10.   A digital signal processor as defined in
claim 2, wherein the presence of a remote digital signal
processor is confirmed by the receipt of incoming DSP
identifiers at said message receiver.

11.   A digital signal processor as defined in
claim 10, wherein the speech decoding function is by-
passed when DSP acknowledgment messages transmitted by a
remote message transmitter are received repetitively at a
local message receiver and the speech encoding function is
by-passed when VSELP information is received at said local
message receiver.

12.   A digital signal processor as defined in
claim 10, wherein the speech encoding/decoding functions
are by-passed when VSELP information transmitted by a
remote message transmitter is received at a local message
receiver.

13.   A digital signal processor as defined in
claim 11, wherein PCM samples are scaled by a raised cosine
window upon transition from VSELP by-pass to non-VSELP by-
pass mode such that a smooth transition is effected.

14.   A digital signal processor as defined in
claim 13, wherein the speech encoding/decoding functions
are reset upon transition from VSELP by-pass to non-VSELP
by-pass mode such that a smooth transition is effected.

15.   A digital signal processor as defined in
claim 11, wherein by-pass mode can be terminated by

instructing the controller to deactivate the message
transmitter.

5   16.   A digital cellular system as defined in
claim 4, wherein each frame of VSELP signal comprises a
VSELP message repeated for each frame for VSELP signal
identification, VSELP encoded user information, a checksum
and a fixed pattern of weak PCM samples.

10   17.   A digital cellular system as defined in
claim 16, wherein said VSELP encoded user information is
written into the least significant entries of an
input/output buffer.

15   18.   A digital cellular system as defined in claim 3,
wherein a remote digital mobile telephone can be alerted of
the occurrence of a CRC error at said first DSP from a
signal arriving from said local digital mobile telephone,
by sending said VSELP signal with CRC state information to
20   said second digital signal processor and subsequently
sending said VSELP signal with a 1's complement of the
calculated CRC to said remote digital mobile telephone for
a first number of consecutive CRC failures, thus alerting
said remote digital mobile telephone of a CRC error.
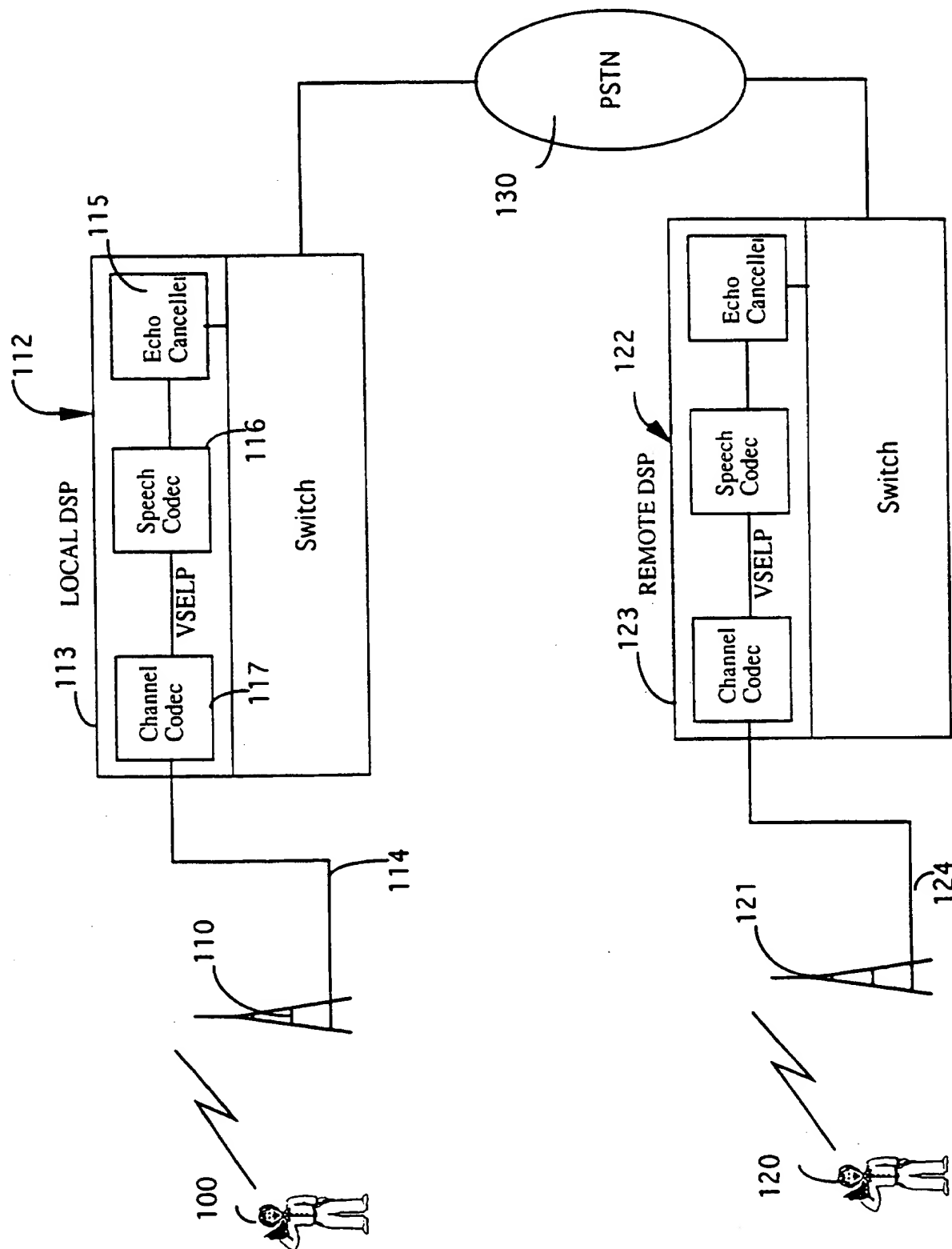
Figure 1

Prior Art
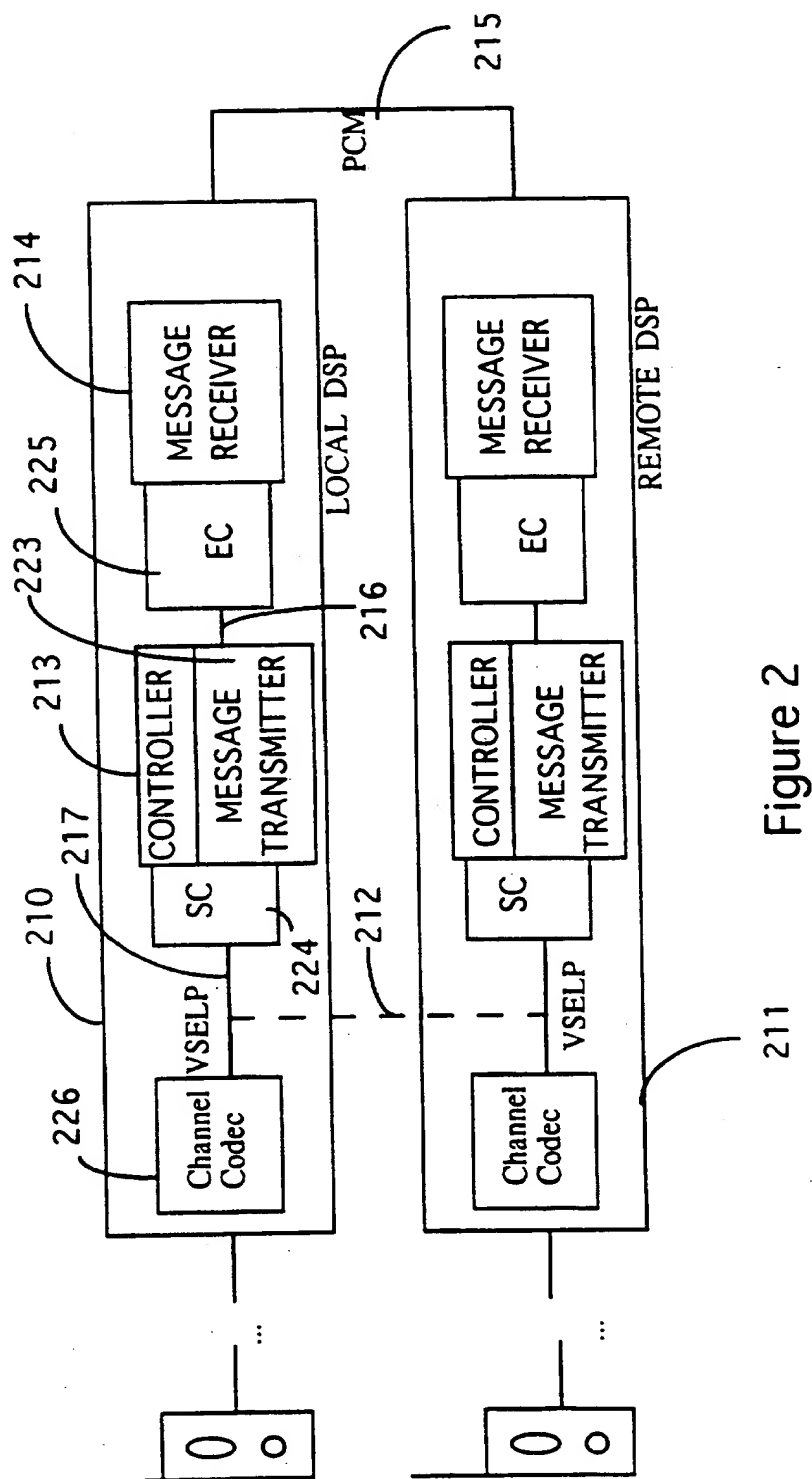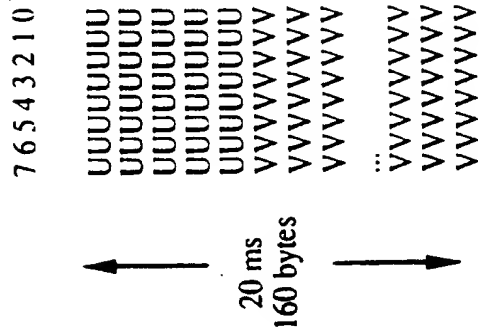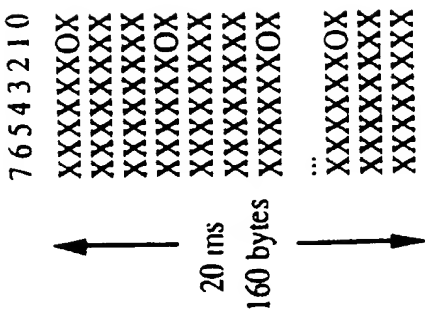
Figure 2

Figure 4

Figure 3
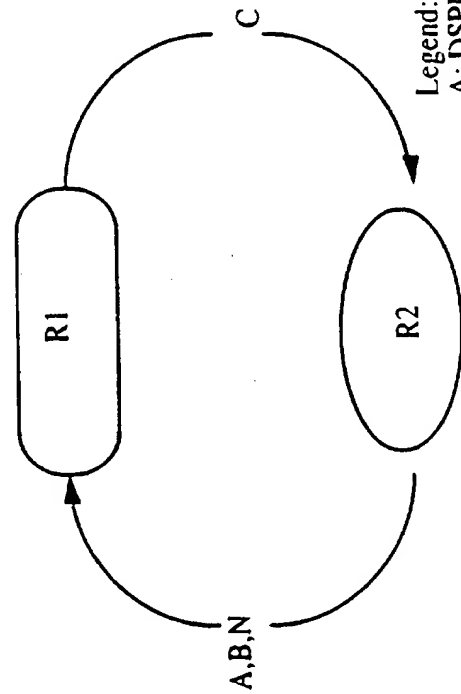
Legend:
A: DSPM Identifier
B: DSPM Acknowledge
C: VSELP message

N: No message

Figure 5

Figure 6

Legend:
A: DSP Identifier
B: DSP   Acknowledge
C: VSELP message
S: Special message
N: No message
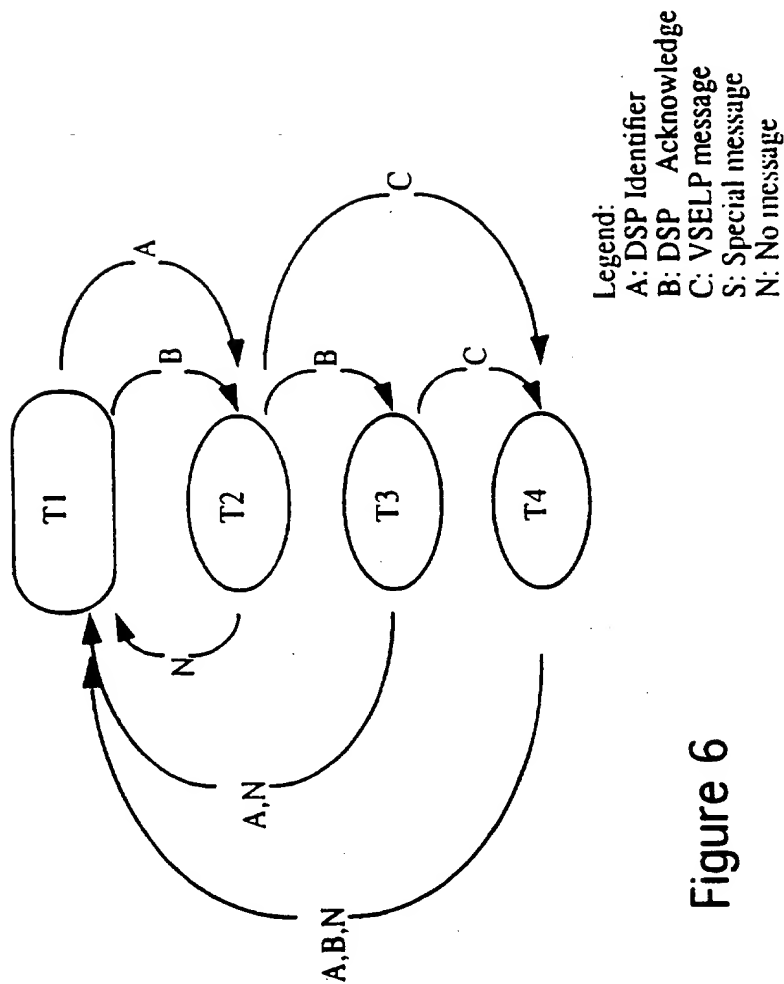
Transmitter State	Output Format	Message to Transmit
T1	PCM	"A" : DSP identifier
T2	PCM	"B" : DSP acknowledgment
T3	VSELP	"C" : VSELP
T4	VSELP	"C" : VSELP

Figure 7

Controller flowchart

Figure 8a

```
              ╱◇╲
        No───╱     ╲
            ╱ New message ╲
            ╲  flag set   ╱
             ╲           ╱
              ╲◇╱
               │
              Yes
               ▼
    ┌─────────────────────────┐
    │ Clear new message flag   │
    └─────────────────────────┘
               │
               ▼
    ┌─────────────────────────┐
    │ Update successive message│
    │   repetition count       │
    └─────────────────────────┘
               │
               ▼
    ┌─────────────────────────┐
    │   Update receiver        │
    │      state               │
    └─────────────────────────┘
               │
               ▼
    ┌─────────────────────────┐
    │  Update transmitter      │
    │      state               │
    └─────────────────────────┘
               │
               ▼
              ╱◇╲
        No───╱     ╲
            ╱ Bypass feature  ╲
            ╱ shut-down control ╲
            ╲ from system or DTMF╱
             ╲ generation request╱
              ╲◇╱
               │
              Yes
               ▼
    ┌─────────────────────────┐
    │ Reset next transmitter   │
    │     state to T1          │
    └─────────────────────────┘
               │
               ▼
    ┌─────────────────────────┐
    │  Set bypass disable flag │
    └─────────────────────────┘
               │
               ▼
         ╭──────────╮
         │  Done    │
         ╰──────────╯
```
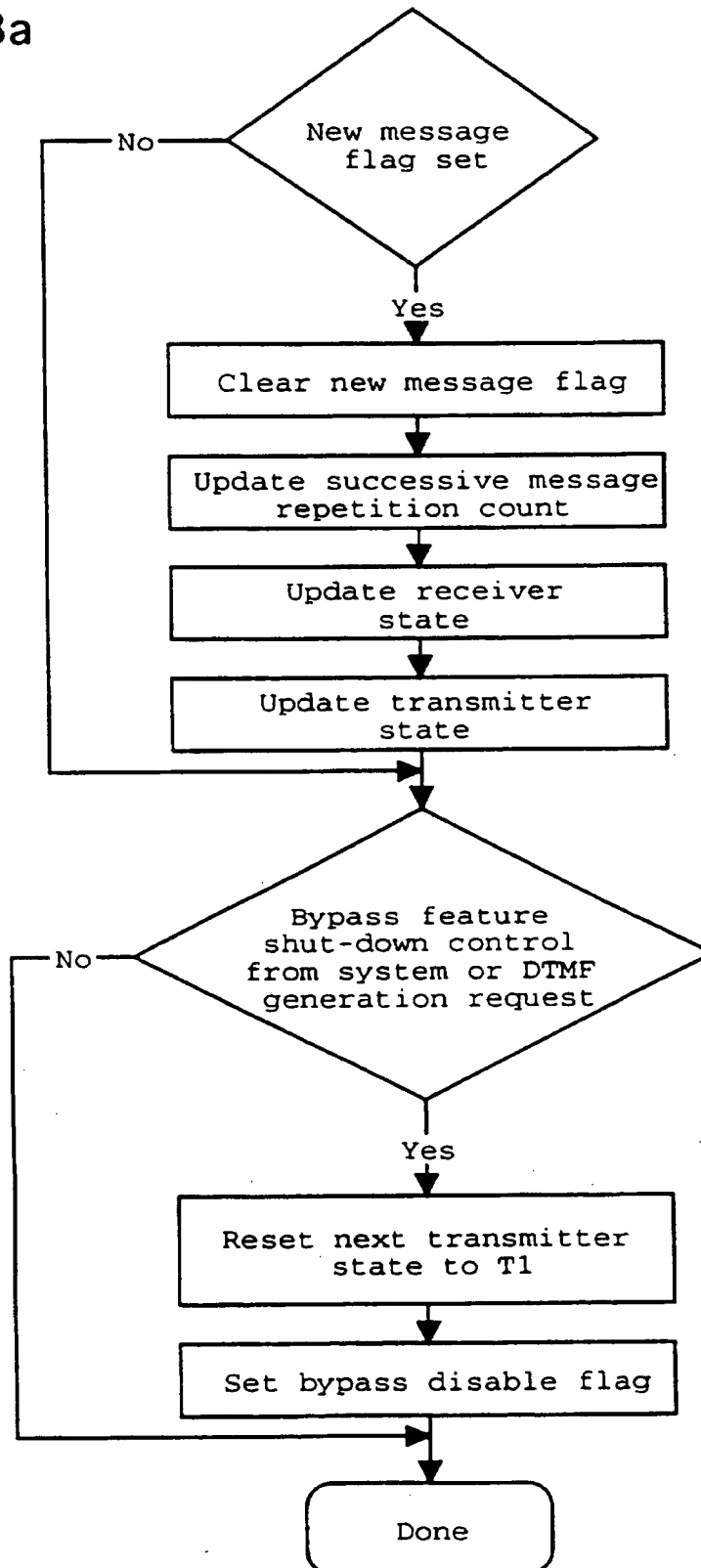
6/16

Controller: Receiver State Update

Figure 8b

```
         ┌─────────────┐
         │   Start     │
         │  Receiver   │
         │   State     │
         │   Update    │
         └──────┬──────┘
                │
                ▼
             ╱──────╲
           ╱          ╲
 No ─────╱ VSELP message ╲───── Yes
  │      ╲   received    ╱        │
  │        ╲          ╱          │
  │          ╲──────╱            │
  │                              │
  ▼                              ▼
┌────────────────┐      ┌────────────────┐
│ Set next receiver│      │ Set next receiver│
│  state to R1    │      │  state to R2    │
└────────┬───────┘      └────────┬───────┘
         │                        │
         └───────────┬────────────┘
                     ▼
              ┌─────────────┐
              │    Done     │
              └─────────────┘
```
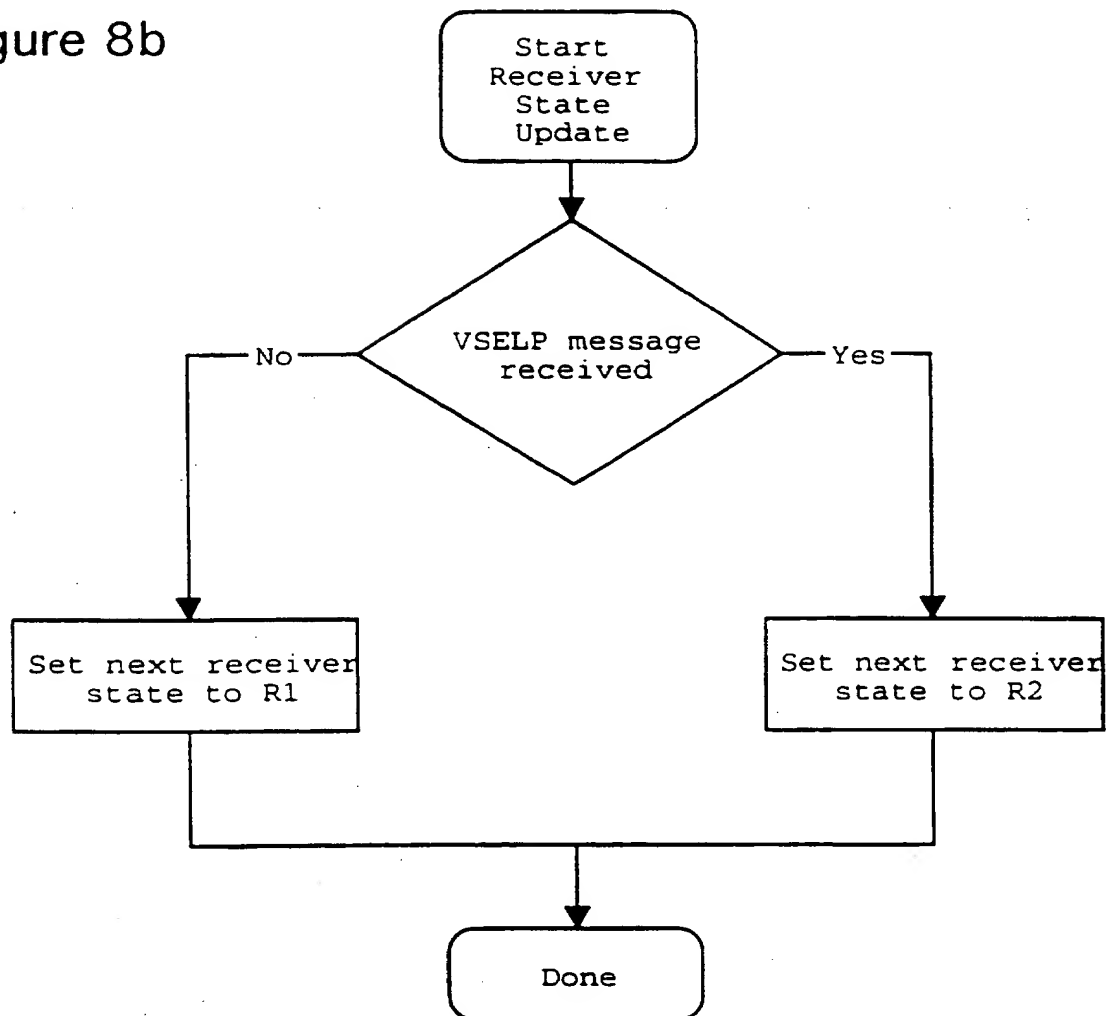
7/16

Controller: Transmitter State Update

Figure 8c

8/16

Controller: Transmitter
State Update (cont.)

Figure 8d

Transmitter flowchart

Figure 8e
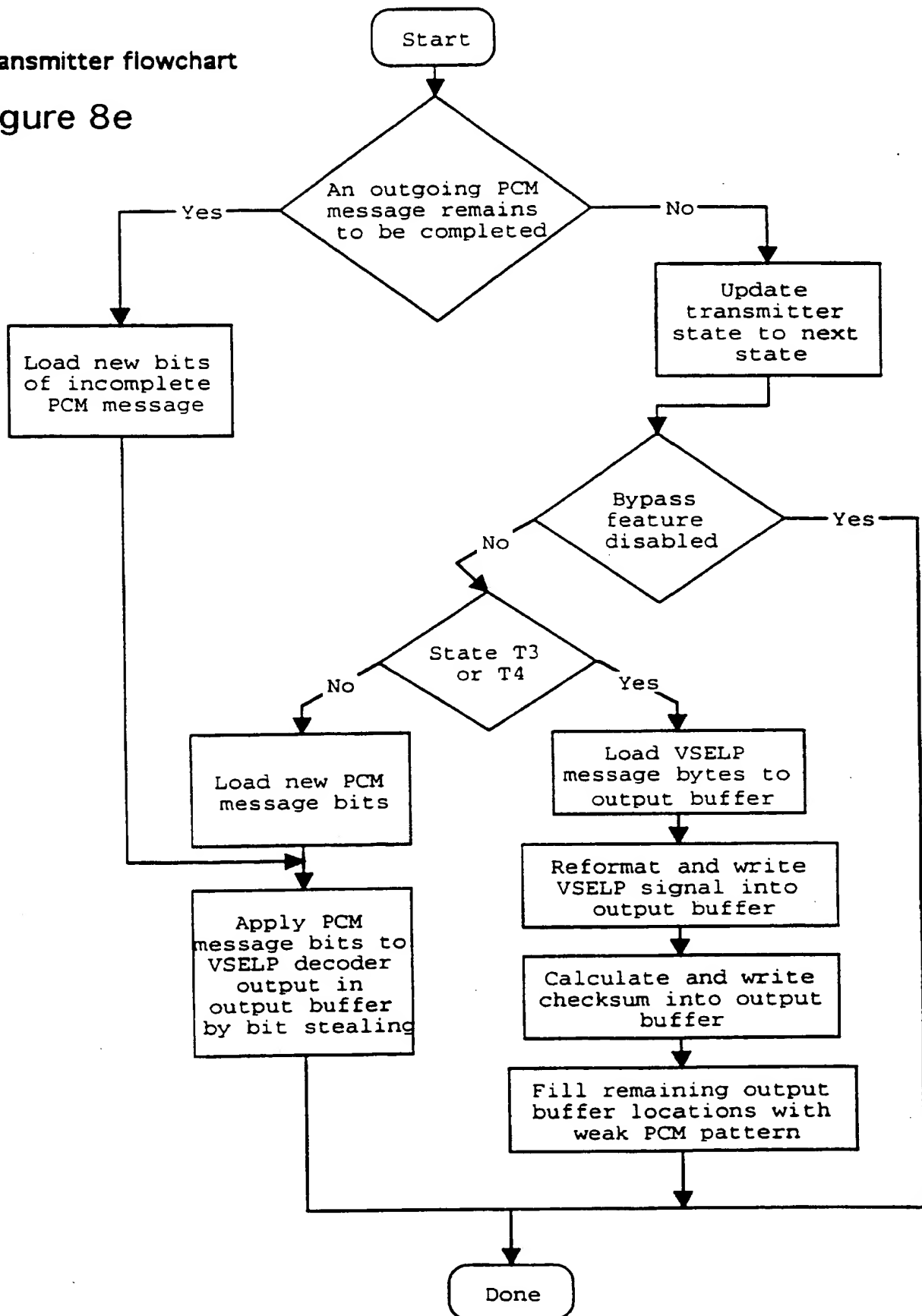
Message Receiver

Figure 8f

```
                              ( Start )
                                 │
                                 ▼
                    ◇ PCM or VSELP message detected
          No ◇─────  in previous remote input frame ─────◇ Yes
          │                                                │
          ▼                                                ▼
  ┌────────────────────┐                      ◇ Current input byte is at
  │ Extract PCM message │                     ◇ beginning of the remote
  │ bit from input byte │                      ◇ input frame
  │ and save it in      │                                 │
  │ memory              │                                Yes
  └────────────────────┘                                 │
          │                                               ▼
          ▼                                    ┌────────────────────┐
  ◇ PCM message formed by                      │ Copy input byte     │
  ◇ new message bit and                        │ into memory for     │
  No ◇ message bits extracted                   │ VSELP message       │
  │  ◇ from previous input bytes                │ detection           │
  │          │                                  └────────────────────┘
  │         Yes                                            │
  │          ▼                                             ▼
  │  ┌────────────────────┐                     ◇ Input bytes collected
  │  │ Set timers for new │              No ◇── from a VSELP message ──◇ Yes
  │  │ PCM and VSELP      │              │                              │
  │  │ message detection  │              ▼                              ▼
  │  └────────────────────┘   ◇ VSELP message received        ┌──────────────┐
  │          │                ◇ in previous remote frame ─Yes  │ Set VSELP    │
  │          ▼                │         │                      │ message flag │
  │  ┌────────────────────┐   │        No                      └──────────────┘
  │  │ Define 20ms framing│   │         │                            │
  │  │ structure of input │   │         ▼                            ▼
  │  │ from remote DSPM    │   │  ┌──────────────┐            ┌──────────────┐
  │  └────────────────────┘   │  │ Declare VSELP│            │ Set new      │
  │          │                │  │ message loss │            │ message flag │
  │          ▼                │  └──────────────┘            └──────────────┘
  │  ┌────────────────────┐   │         │
  │  │ Set PCM message flag│  │         ▼
  │  └────────────────────┘   │  ┌──────────────┐
  │          │                │  │ Reset message│
  │          ▼                │  │ flag         │
  │  ┌────────────────────┐   │  └──────────────┘
  │  │ Set new message flag│  │
  │  └────────────────────┘   │
  │          │                │
  ▼          ▼                ▼                                ▼
( 1 )     ( 2 )            ( 3 )                            ( 4 )
```
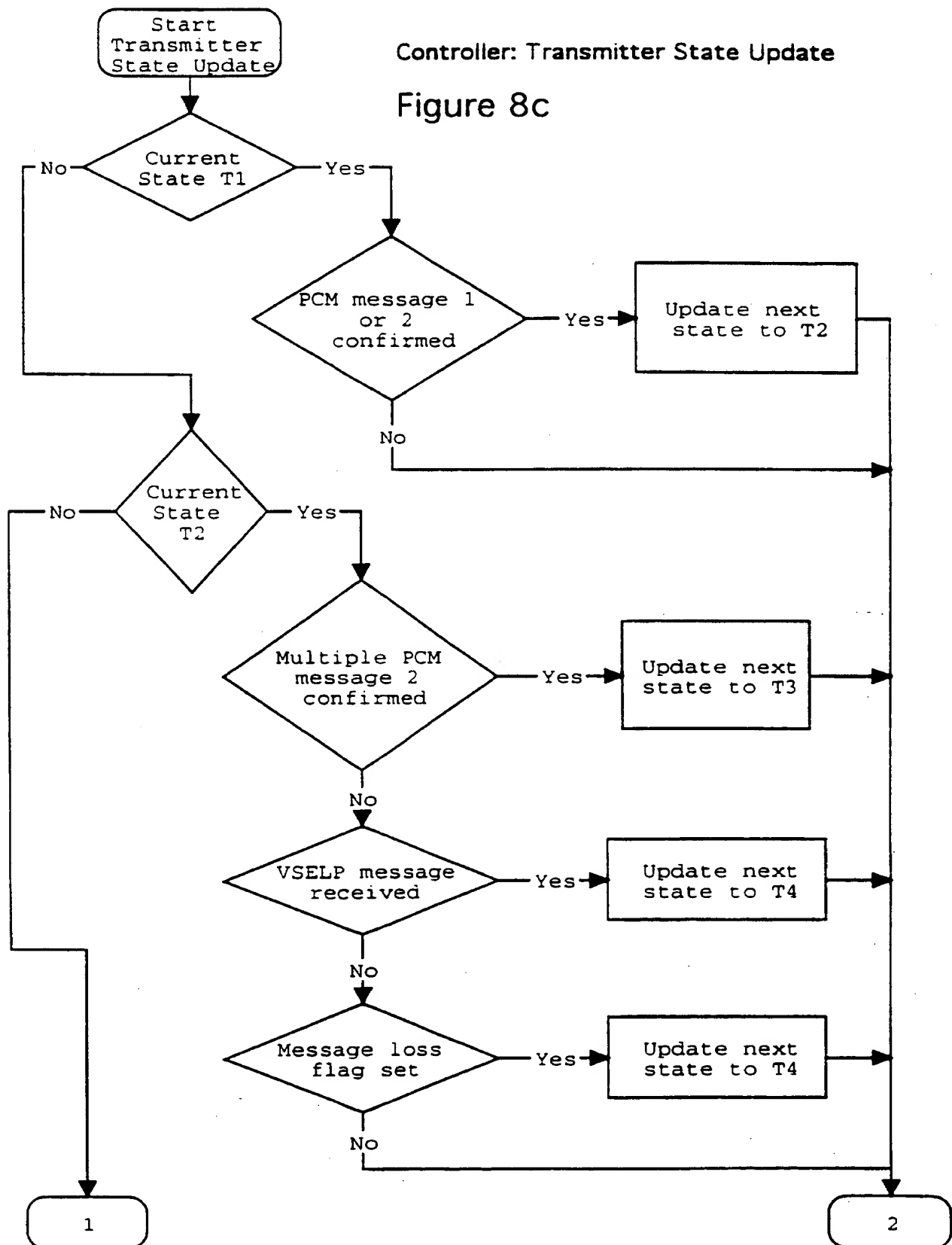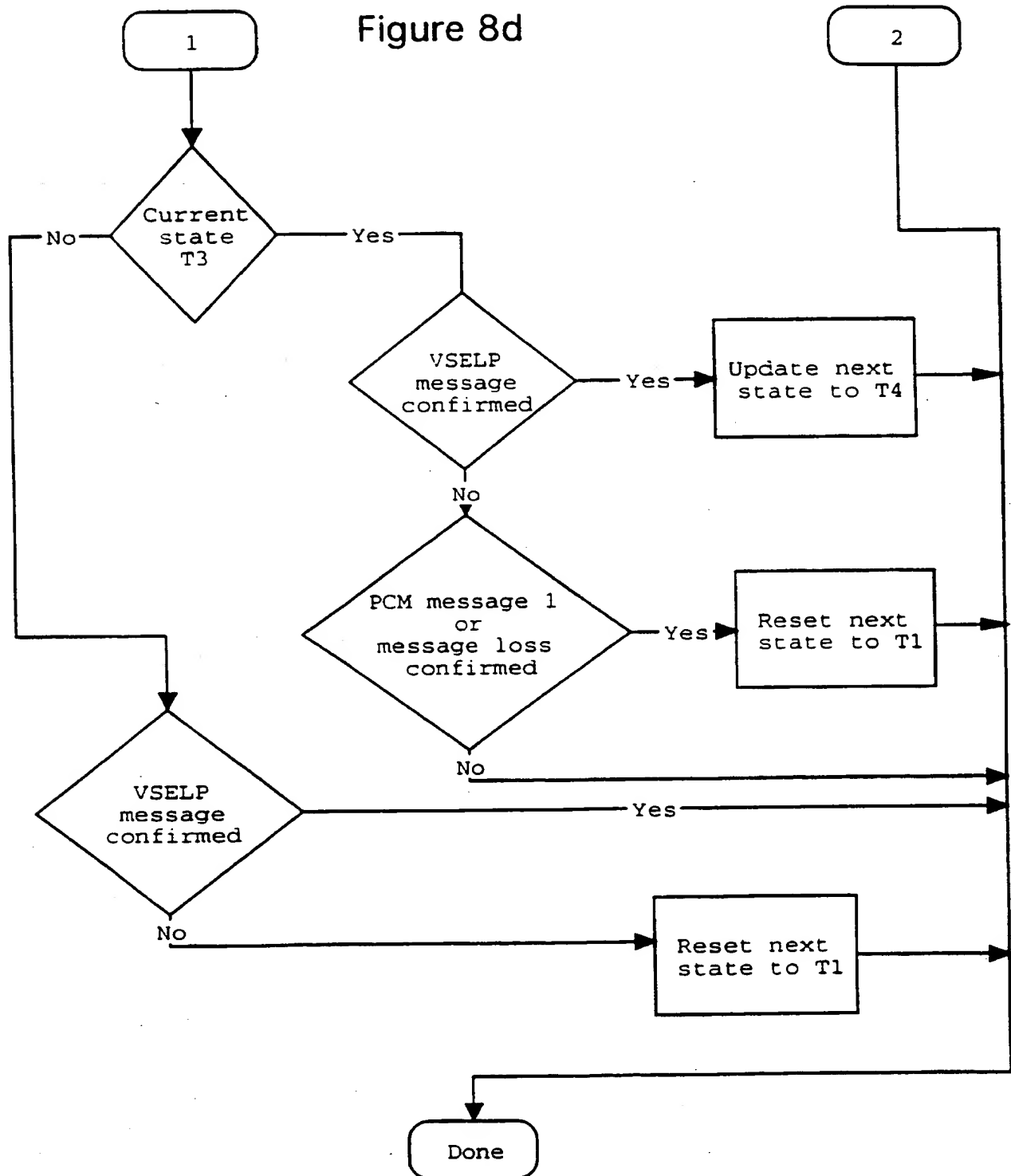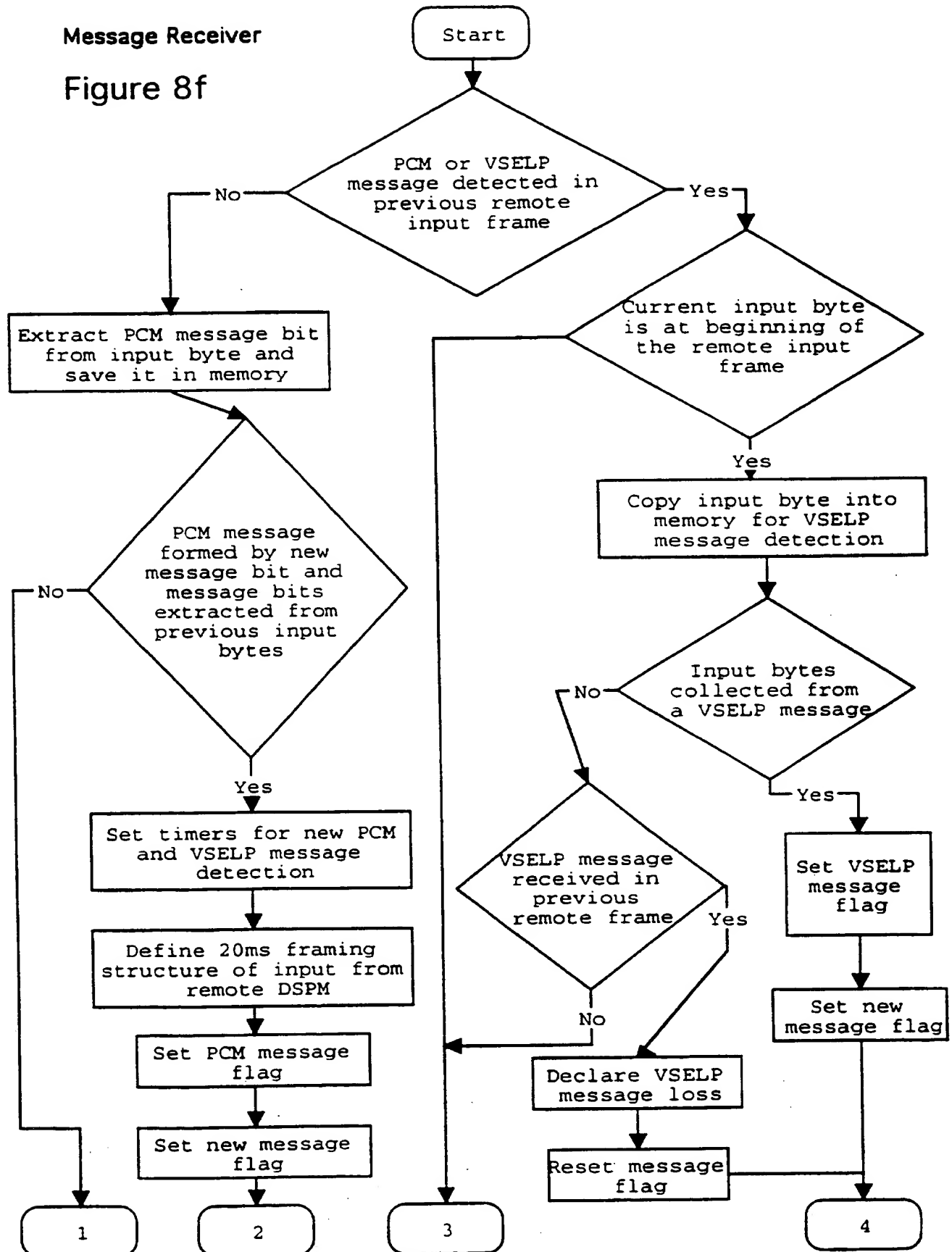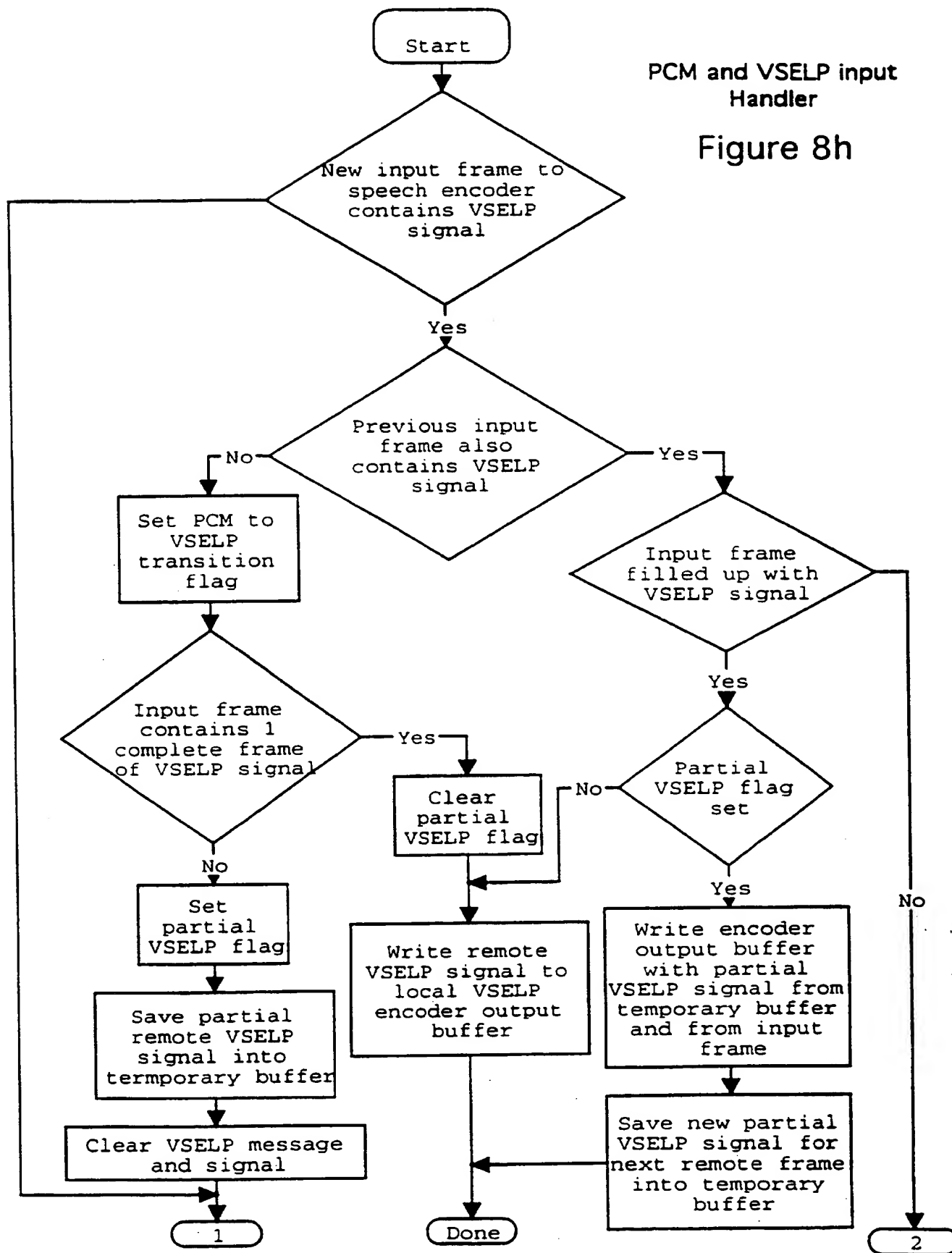
Message Receiver (cont.)

Figure 8g

Start

PCM and VSELP input
Handler

Figure 8h

New input frame to
speech encoder
contains VSELP
signal

Yes

Previous input
frame also
contains VSELP
signal

No — Set PCM to
VSELP
transition
flag

Yes — Input frame
filled up with
VSELP signal

Input frame
contains 1
complete frame
of VSELP signal

Yes — Clear
partial
VSELP flag

No

Set
partial
VSELP flag

Save partial
remote VSELP
signal into
termporary buffer

Clear VSELP message
and signal

Yes

Partial
VSELP flag
set

Yes

Write encoder
output buffer
with partial
VSELP signal from
temporary buffer
and from input
frame

No

Write remote
VSELP signal to
local VSELP
encoder output
buffer

Save new partial
VSELP signal for
next remote frame
into temporary
buffer

1

Done

2

Figure 8i

PCM and VSELP input Handler (cont.)

14/16
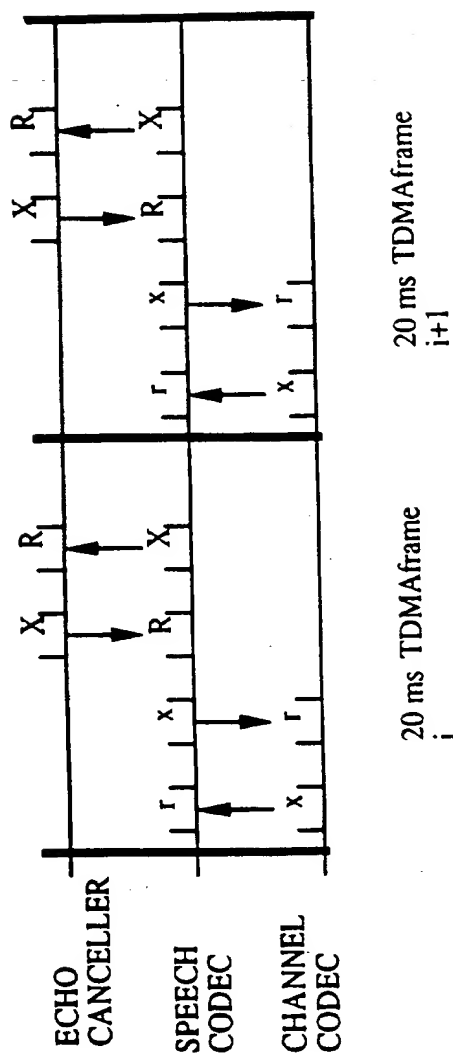

Figure 9

r : receive VSELP signal
x: transmit VSELP signal
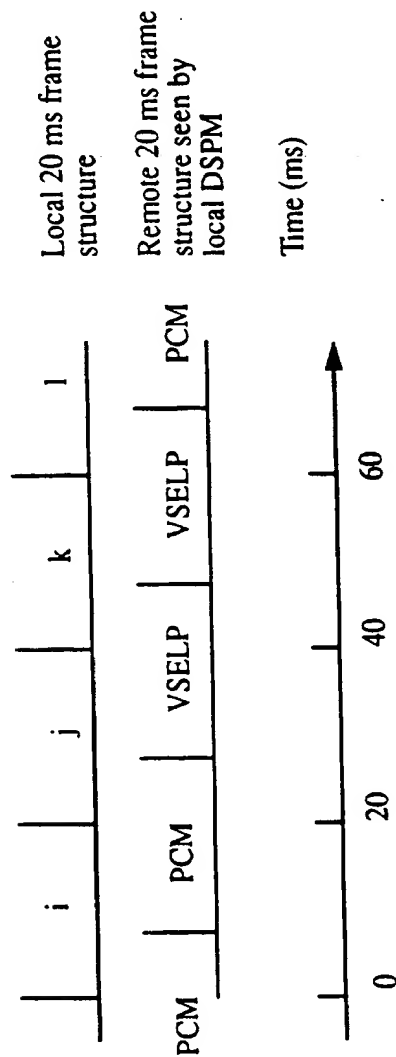R: receive PCM/VSELP signal
X:transmit PCM/VSELP signal

Figure 11

15/16

| VSELP Parameter	Bits	Definitions
STATE	3	CRC
LPC1	6	1st reflection coefficient
LPC2	5	2nd reflection coefficient
LPC3	5	3rd reflection coefficient
LPC4	4	4th reflection coefficient
LPC5	4	5th reflection coefficient
LPC6	3	6th reflection coefficient
LPC7	3	7th reflection coefficient
LPC8	3	8th reflection coefficient
LPC9	3	9th reflection coefficient
LPC10	2	10th reflection coefficient
R0	5	frame energy
LAG1	7	lag for 1st subframe
CODE1_1	7	1st codebook code for 1st subframe
CODE2_1	7	2nd codebook code for 1st subframe
GSP0_1	8	excitation gains index for 1st subframe
LAG2	7	lag for 2nd subframe
CODE1_2	7	1st codebook code for 2nd subframe
CODE2_2	7	2nd codebook code for 2nd subframe
GSP0_2	8	excitation gains index for 2nd subframe
LAG3	7	lag for 3rd subframe
CODE1_3	7	1st codebook code for 3rd subframe
CODE2_3	7	2nd codebook code for 3rd subframe
GSP0_3	8	excitation gains index for 3rd subframe
LAG4	7	lag for 4th subframe
CODE1_4	7	1st codebook code for 4th subframe
CODE2_4	7	2nd codebook code for 4th subframe
GSP0_4	8	excitation gains index for 4th subframe

Figure 10
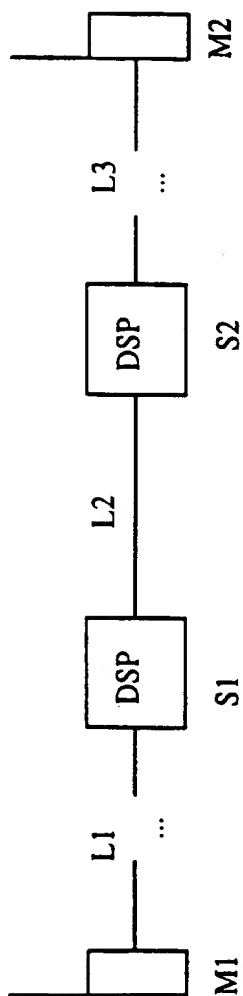
Figure 12

A. CLASSIFICATION OF SUBJECT MATTER

IPC 6   H04Q7/30

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6   H04Q   H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	-/--	

☒ Further documents are listed in the continuation of box C.   ☒ Patent family members are listed in annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
15 March 1996	19. 04. 96

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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